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Some caveats about the evolution of the N/O abundance and the star formation history.

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Abstract. We carefully analyze how the abundance of Nitrogen over Oxygen evolves when dependent on metallicity stellar yields with a primary component of N proceeding from AGBs stars are used. We show the results obtained with a chemical evolution models grid, calculated with variable star formation efficiencies, which produce different star formation histories. Finally we see how the N/O abundance is related on the evolutionary history.

Key words. Galaxy: abundances – Galaxies: abundances – Galaxies: Star formation

1. Introduction

Nitrogen abundances when compared with the Oxygen one, N/O, may, in principle, inform about the time in which low and intermediate mass (LIM) stars formed, and, consequently, when the widest episode of star formation took place. This idea is based on the stellar mean-lifetimes for LIM stars, main producers of N, which are longer than the ones of massive stars, which eject O to the interstellar medium (ISM).

The data, however, must be carefully interpreted before to reach misleading conclusions based in this simple scheme. If a mass of gas form a bulk of stars simultaneously, in a Single Stellar Populations (SSP), it is true that N will appear after O in the ISM, with a certain time delay. However, when data proceeding from different galaxies or different regions within a galaxy, are compared, the previous scenario is not longer valid, since a) most of data refers to spiral and irregular galaxies, where the star formation is a continuous process and, due to that, there are a mix of SSPs; and b) the observations correspond to the final stage after an evolutionary path object, and galaxies follow different tracks.

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2. Using the Closed Box Model

2.1. The basic scenario

N may be primary, NP, created directly from the original H by the corresponding nuclear reactions, or secondary, NS, if there exists a seed of C or O in the gas with which the star formed. Then the production is proportional to the original oxygen abundance. N is mainly produced as secondary in both massive and LIMs stars. But in LIM stars a fraction of N is created as primary in the third dredge-up and Hot Bottom Burning processes Renzini & Voli (1981). In massive stars N the stellar rotation provokes the increase of NP, specially at the lowest metallicities, (Ekström et al. 2008).

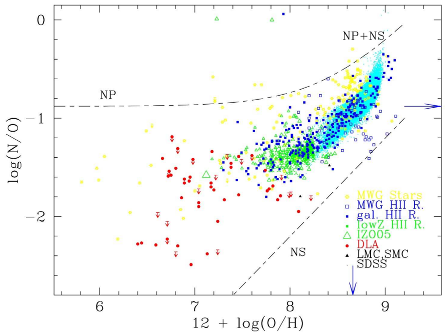

Fig. 1. The nitrogen over oxygen ratio, as $\log(N/O)$, as a function of the oxygen abundance, as $12 + \log log(O/H)$, for a wide sample of data as coded: MWG stars and HII regions; Other galaxies HII regions, (low metallicity objects shown separately), Damped Lyman Alpha, and SDSS estimates from Liang et al. (2006)

Following the well known Closed Box Model (CBM Tinsley 1980), the abundance of metals, Z, in a region may be expressed by the equation: $Z = pln\mu^{-1}$, where $\mu = M_{gas}/M_{tot}$ is the gas fraction in that region and p is the integrated stellar yield, the elements newly created by a stellar generations of stars (by assuming that all stars that produced metals are already died). By applying this equation for N and O, and assuming that both are primary:

$$\frac{Z_N}{Z_O} = \frac{p_N}{p_O} = constant \quad (1)$$

where Z_O and Z_N are the Oxygen and Nitrogen abundances, and p_O and p_N are the corresponding integrated stellar yields.

If N is secondary, then:

$$\frac{Z_N}{Z_O} = \frac{p_N(O)}{p_O} \sim O \quad (2)$$

We plot these theoretical lines in the diagram N/O *vs* O/H, Fig. 1. The first case appears as an horizontal line while the second one would be represented by a straight line with a certain slope[1]. When both contributions there exist, the horizontal line begins to increase from a certain oxygen abundance. We also plot the observations in this Fig. 1 (see references in Mollá et al. 2006). It is evident from this diagram that both components of N are necessary.

[1] Both lines are drawn with arbitrary yields

Since LIM stars produce N by both processes, such as most of authors establish (see Gavilán et al. 2006, thereinafter GAV06, and references therein), it is immediate to try to explain the data by using the corresponding yields of LIM and massive stars. In this work we show how N/O evolves when a contribution of NP proceeding from LIM stars there exists.

Some people think that low metallicity objects must be young, linking wrongly *oxygen abundance– time*, and, therefore assume that they have not sufficient time to eject N from LIM stars. Because of that they search for other way to obtain NP.

However, this idea that links low oxygen abundance to short evolutionary time is a mistake: *The oxygen abundance is not a time scale.* It is possible to have a high oxygen abundance in a very short time, or a very low one even in an object which exists since a long time ago if it evolves very slowly (Legrand 2000).

2.2. By taking into account the stellar mean-live-timescales

It is possible to solve the equation of the CMB for both components by assuming that there are two classes of stars, the massive ones, $m \geq 8M_{\odot}$, which create O and secondary N, and the intermediate stars, $4 \leq m \leq 8M_{\odot}$, which eject primary N, too. The resulting expression is given by Henry et al. (2000) as:

$$Z_N = \frac{p_{NS}\,p_C}{2p_O^2}Z_O^2 + \frac{p_{NS}\,p_C}{6p_O^2}Z_O^3 + \frac{p_{NP}}{p_O}(Z_O - Z_\tau)e^{\frac{Z_\tau}{p_O}} \quad (3)$$

where Z_i is the abundance of each element, C, N, or O, p_i is the corresponding yield, and the subscript NP and NP refer to the the component primary and secondary.

Following that, N begins as secondary, when massive stars die, what means that N/O evolves over an straight line with a certain slope. After a delay time τ, in which the oxygen abundance Z_O reaches a value Z_τ, the NP

ejected by LIM stars appears in the ISM. Just in that moment Z_N increases exponentially, due to the last term of the equation, until to arrive to the primary N level. The behavior simulates a phase change, that occurs exactly when the first stars eject NP, time defined by the most massive LIM stars stellar mean-lifetimes.

If these stars have 2, 4 or 8 $M_\odot$, their mean-lifetimes are $\sim$ 220, 100 and 40 Myr, respectively, such as it is obtained from the functions (Fig. 2) given by the usual used Padova, Geneve stellar tracks or from Bazan & Mathews (1990). The evolutionary tracks resulting of the above Eq. 3 are represented in Fig. 3, panel a).

The N/O abundance ratio increases abruptly when the oxygen abundance is Z_τ, which takes a different value for 2, 4, or 8 $M_\odot$: The smaller the stellar mass, the higher the O abundance Z_τ at which the exponential function appears and the N/O increases, such as we show in Fig. 3a). From this plot, we could say that, in a Single Stellar Population in which NP is ejected by only a value of stellar mass, if, for a given O abundance, N/O is close to the secondary line, their stars are, in average, younger than those ones with a higher value of N/O, nearer to the primary line.

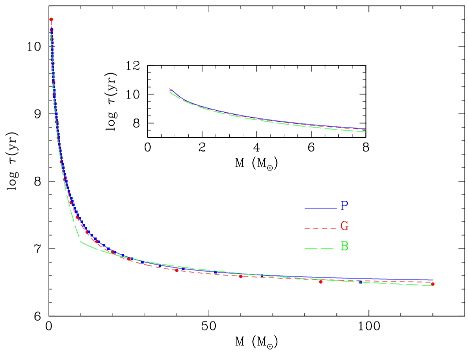

Fig. 2. The stellar mean-live-timescales as a function of the stellar mass, as obtained from Padova's group (P), (Bressan et al. 1993), Geneve's (G) group (Meynet & Maeder 2002) stellar tracks, or as given by Bazan & Mathews (1990) (B).

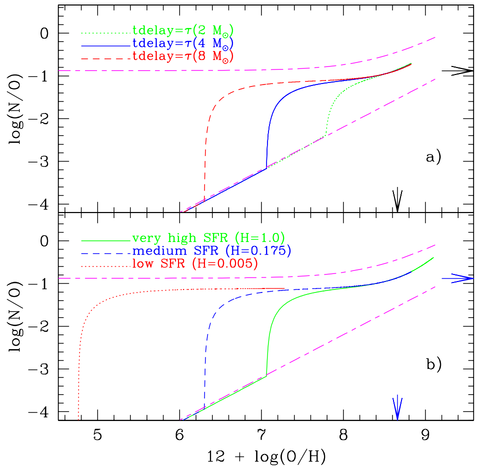

Fig. 3. The evolution of N/O, as log(N/O) *vs* O/H, as 12+log(O/H) following Eq. 3 a) for stars with different masses ejecting NP, as labelled and b) for stars of $4M_\odot$ ejecting NP but where the star formation occurs with different efficiencies.

2.3. The star formation efficiencies

However, this is not the complete history. In order to obtain the abundance Z_τ, following Eq. 1, it is necessary to know the gas fraction, a quantity that may change with time. Let assume that the galaxy starts with a value $\mu = 1$, what means that the mass is completely in gas phase, and that it decreases when stars form[2]. If we assume that the gas mass g depends on time as: $\frac{dg}{dt} = -Hg$, then $g = g_0 e^{-tH}$, the mass on stars is $s_* = g_0(1 - e^{-tH})$, and $\Psi = \frac{ds}{dt} = Hg$, where H is the efficiency to form stars. In that case the star formation law results an exponentially decreasing function of the time: $\Psi(t) = \Psi_0 e^{(-t/t_0)}$, being the time-scale t_0 the inverse of H. If H is high, the gas will consume very quickly and, therefore, the gas fraction $\mu = g/(g + s)$ takes a small value in a very short time. Obviously if H is small, the gas fraction maintains near from 1.

We show the evolution of $\mu(t)$ in in Fig. 4a) for some values of H as labelled. The Oxygen

[2] Note that other evolutionary scenarios are possible

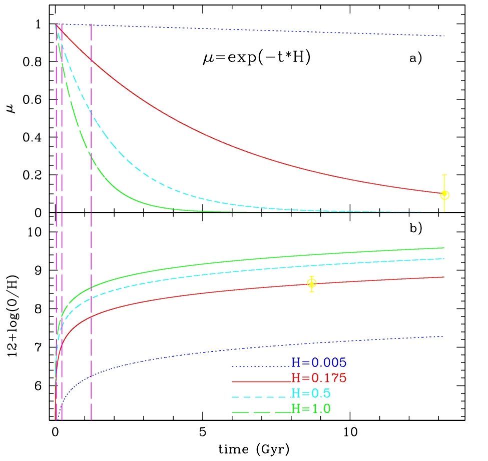

Fig. 4. The evolution of a) the gas fraction μ and b) the oxygen abundance $12 + log(O/H)$ for different values of star formation efficiency as labelled. The solar region value is marked as a (yellow) solid large dot. The solar value of the oxygen abundance is plotted at 8.7 Gyr by assuming that Sun born 4.5 Gyr ago.

abundance evolves according as shown in Fig. 4b).

Over-plotted on both graphs there are 3 lines corresponding to times, in increasing order, equal to the mean-lifetimes of stars with 8,4 and 2 $M_{\odot}$. We obtain 3 different values for the oxygen abundance Z_{τ} for each evolutionary line. Equivalently, different oxygen abundances Z_{τ} for each stellar mass are obtained, depending on H. If we assume that stars of 8 $M_{\odot}$ produce NP, Z_{τ} is $\sim$ 8, 7.2, 6.8 or even $\leq$ 6 for H= 1, 0.5, 0.172 or 00005 in a time of 40 Myr. That is, the NP appear in the ISM at an abundance that may be as lower as $12 + \log{(O/H)} = 6$ if the efficiency to form stars is very low, or as higher as 8, if the efficiency is high, but always in a same time scale as short as 40 Myr.

We show in panel b) of Fig. 3 the evolution of the relative abundance log(N/O) *vs* the oxygen abundance $12 + log(O/H)$ for three values of star formation efficiencies by assuming that NP is ejected by stars of 4 $M_{\odot}$. We see a similar behavior to that one shown in panel a).

3. The metallicity dependent stellar yields

The previous section results are obtained by taking constant effective yields p_{NP}, p_{NS} and p_O. Actually, the stellar yields depend on the metallicity Z with which stars form. And therefore the effective yield for a single stellar population also depends on Z. In the case of LIM stars, this question is even more important since, obviously, the proportion NP/N must change with Z. If the star has a very low Z, the abundance of O, the seed for the NS, is also low, so most N is created as NP.

This is clearly seen in Fig.2 from GAV06 where this proportion NP/N is represented as a function of the stellar mass for some sets of stellar yields from the literature. In panel a) the solar abundance yields from Gavilán et al. (2005); van den Hoek & Groenewegen (1997); Marigo (2001, hereinafter BU,VG, and MA, respectively) are represented. In panels b), c) and d) the same is shown for two values of Z for each one of these sets separately, as labelled. In all cases, NP/N is higher for the low Z set than for the solar abundance one.

The dependence on Z of the integrated yields for a simple stellar population is shown in Fig.3 from GAV06. In panel a) the integrated yield of N tends to be larger for higher Z. In panel b) the ratio p_{NP}/p_N clearly decreases with Z, such as it must do. The different sets, however, have different behaviour. BU has smaller total yields of N than VG and more similar to values from MA, but the dependence on Z is smoother that this one shown by VG and MA.

By using dependent yields on the CBM equation of the previous section the results shown in Fig 5 are obtained. Results for different efficiencies H, low, solar and high, are in panels a), b) and c) as dotted lines. The main effect of changing yields with Z is that evolutionary tracks elongate when the star formation rate is strong, as it occurs in c). Therefore the efficiency to form stars, which define the shape of the star formation history, the level of starburst with which the stars form, is essential to obtain an elongated or flat evolutionary track in the plane NO-OH.

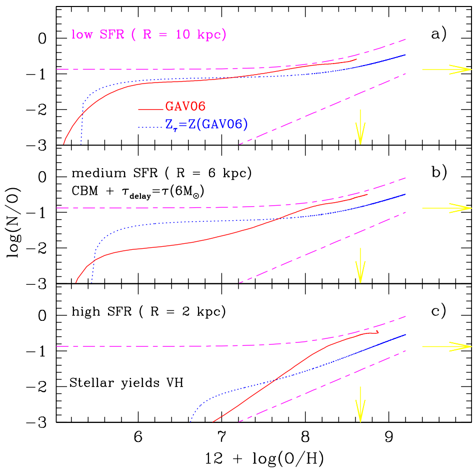

Fig. 5. The evolution of log(N/O) as a function of 12+log(O/H) for different star formation rates: a) low, b) intermediate and c) high efficiency, respectively. Dotted lines are the CBM results while the solid lines are the results obtained by GAV06 for different regions of the MWG disk.

4. The chemical evolution model grid

4.1. The local universe

Until now only CBM results have been analyzed. However modern chemical evolution models are usually numerical codes that include a larger quantity of information, taking into account the mean-lifetimes of stars, the IMF, the stellar yields, a large number of elements, etc. We have over-plotted in Fig. 5, with solid lines, the results from GAV06, obtained by using the multiphase chemical evolution model (Ferrini et al. 1994; Mollá & Díaz 2005) with the VG stellar yields for different regions of the Milky Way Galaxy (MWG), located at 10, 6 and 2 kpc of galactocentric. They are similar to those for the CBM.

Following the same scenario than GAV06, we have compute models for 44 sizes or masses of galaxies and 10 values of efficiencies in the range [0,1] for each one of them (see Mollá & Díaz 2005; Mollá et al. 2006, for details). The results for the present time are shown in Fig. 6 with large open dot while the small (grey) dots represent the SDSS data and

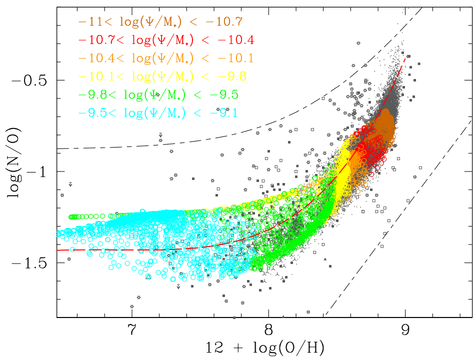

Fig. 6. Multiphase chemical evolution model results for the present time for a grid of 440 galaxies as open dots. Small dots in the background are the SDSS data and the other symbols are extragalactic and Galactic HII regions data as labelled.

other HII regions data from the literature. Our results even reproduce the high dispersion observed in the plane NO-OH: there are two regions where the dispersion is higher, one located around (7.8, -1.45) and a second one around (8.7,-1), just where the low mass and the bright massive galaxies fall.

These models demonstrate clearly that efficiencies to form stars have an important role in the evolution of the tracks in the plane NO-OH, and are essential to reproduce the data.

4.2. The star formation history role

Mallery et al. (2007) have shown that the location of a galaxy in the plane NO-OH is related with the specific star formation rate, the star formation rate by stellar mass unit, sSFR. They found that the highest values of N/O correspond to the smallest values of sSFR.

Since we also reproduce this trend, as we may see with different code of colors in Fig.6, we may explain the subjacent reasons for this correlation. In our models the smallest sSFR occur in galaxies where the star formation was high in the past, in the earliest times of evolution. The gas was rapidly consumed and therefore the star formation rate decreased since then, showing now very small values. On the opposite side, when the efficiency to form stars

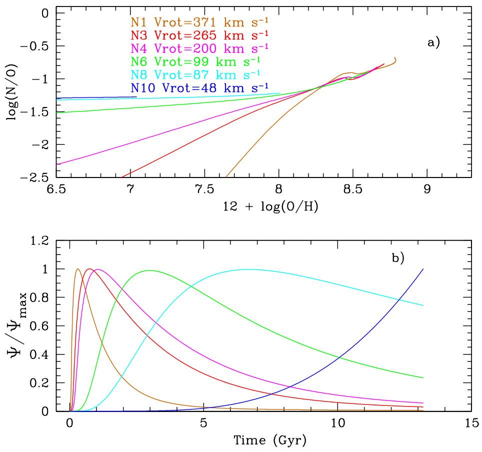

Fig. 7. a) Evolutionary tracks for six different theoretical galaxies in the plane No-OH, b) Star formation histories for the same 6 models

is very low, the star formation history increases with time, and, because of that, the present star formation rate is high. The evolutionary track of an object and its final point in the NO-OH plane depends on the star formation history suffered by the galaxy. In order to demonstrate that, we show in Fig. 7a) 6 different evolutionary tracks in the plane NO-OH and the corresponding star formation rate in panel b) of the same figure.

The low mass galaxies with low efficiencies have not had a high star formation in the past, and they may considered young from the point of view of the averaged age for most of their stars, created mainly in recent times. But they also have old stars able to eject nitrogen, that was processed as primary, since in that moment Z was very low.

5. Conclusions

The present day data as well as the high-redshift trends in the plane O/H-N/O may be reproduced with chemical evolution models using stellar yields where LIM stars create a certain quantity of NP

Differences in the star formation histories of galaxies are essential to reproduce the data and the observed dispersion, the present position of a galaxy in the diagram N/O vs O/H being determined by this evolutionary history

It is possible to have NP ejected by LIM stars even at a low O abundance since O abundance is not a time scale.

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